which represents the relation between yield of wheat for England and the previous autumn rainfall is:

Yield = 39.5 bushels per acre — 5/4 (previous autumn rainfall in inches).

If we call the yield obtained from the rainfall by this equation the "computed yield," a comparison with the actual yield for the twenty-one years shows that the computed yield agrees with the actual yield within half a bushel in seven years out of the twenty-one. In fourteen years the agreement is within two bushels; in the remaining seven years the difference between computed and actual yield exceeds two bushels. The extreme variation of yield in the twenty-one years is nine bushels, from 26 bushels per acre in 1892 and two other years, to 35 bushels per acre in 1898.

Of the seven years for which the formula gives yields differing from the actual by upward of two bushels, 1896 is the most conspicuous; its actual yield exceeds the computed yield by 4.5 bushels.

These seven years all show anomalous seasons. Taken *seriatim*, they are 1887, 1888, 1893, 1895, 1896, 1899, and 1903.

In 1888 and 1903 the crops were washed away by ten inches of rain in the summer; 1893 is the year of phenomenal drought and the crop was below the computed figure by 2.5 bushels. The years 1892 and 1899 are interesting, because, though the amounts of rain were up to the average, the former had eight dry weeks and the latter ten dry weeks out of the thirteen included in the conventional autumn. They were thus dry autumns, the average amount of rainfall being made up by a few exceptionally wet weeks. The yields correspond with dry autumn values. They are above the average and above the computed figures by some two or three bushels per acre.

There remain 1895 and 1896; 1895 was the year of remarkably cold weather, and in that year the yield fell short, but in the following year the deficiency was made up by a yield as much above the computed value as the previous one fell short. It would appear that in this instance the productive power not utilized in the year of the great cold was not lost but stored. On the other hand, it must be remarked that 1896 had the advantage of a specially dry winter.

It appears from these considerations that the dryness of autumn is the dominant element in the determination of the yield of wheat of the following year. The averages of yield and of rainfall are taken over very large areas, and it may be taken for granted that the investigation of the question for more restricted areas would introduce some modification in the numerical coefficients, if not in the form of the relation.

The data for making such an investigation are not yet in an available form. A comparison has been made between autumnal rainfall for "England, East" and the average yield for the counties of Cambridge, Essex, Norfolk, and Suffolk, which shows a similar relation but a magnified effect of autumnal rainfall upon the crop, and also two exceptional years which have not yet been investigated.

CONTRIBUTIONS TO MARINE METEOROLOGY.

Two important contributions to the meteorology of the sea have recently appeared:

1. *Observations océanographiques et météorologiques dans la région du courant de Guinée. (1855-1900.) I. Text et tableaux. II. Planches.* Utrecht. 1904.

This work, which is published by the Royal Meteorological Institute of the Netherlands, is a thorough discussion of the winds, currents, air pressure, air temperature, number of rainy days, surface temperature, and density of sea water for the region indicated in the title. All the above-named features are fully charted. The region covered by this work lies between the parallel of 25° north and the equator, and the meridians of 0° and 40° west.

2. *Wind charts for the South Atlantic Ocean.* Published by the Hydrographic Department of the British Admiralty, January, 1904.

These charts embrace the region lying between the equator and 65° south latitude, and between the meridians of 20° east and 90° west. Except for small areas in the extreme south of this region, for which observations are lacking or insufficient, wind-roses are given for each 5-degree square; and many useful notes are added regarding local peculiarities of wind and weather. The charts include isobars and isothems. The introduction contains a very interesting and practical discussion of the meteorology of the whole region, together with charts showing the distribution and frequency of fog. This work embodies the results of nearly a million observations. Some portions of these results, dealing with the regions adjacent to the South American coast, were published in 1902.—*C. F. T.*

HIGH WATER IN THE GREAT LAKES.

By Prof. ALFRED JUDSON HENRY.

Very great interest has recently centered in the fluctuation in level of the Great Lakes during the last ten years, the revival in interest being directly due to the unusually high water of 1904. A decided rise in level above what may be called normal stages means greatly increased earning capacity, especially for the larger vessels afloat on these inland seas. In a recent issue of the Chicago Chronicle comparisons were made between low water of 1895 and high water of 1904. The extreme range, about three feet, was shown to have occurred on Lake Ontario, and the least range, about one-tenth of a foot, on Lake Superior. The rise on Lakes Michigan and Huron from 1895 to 1904 was shown to have been a little over a foot and a half and on Lake Erie nearly two feet. It should be remembered in this connection that the low water of 1895 was the culmination of one of the greatest droughts this country has ever experienced. In that year severe and prolonged drought centered in the Lake region and the Middle Atlantic States, and the lowest water of a quarter of a century was reached in many of the rivers and small streams. This period of drought was followed by years of plentiful precipitation, and the Great Lakes, as well as the rivers, returned to normal conditions.

Two distinct series of oscillations are recognized on the Great Lakes. The first consists of the annual rise of the waters to a maximum stage in summer, followed by a decline to a minimum stage in winter or spring. The second series is superposed upon the first, and generally extends through a period of several years. It is illustrated on the diagram, fig. 1, by the upward tendency shown on the curve for Lakes Michigan and Huron from 1896 to 1899; also on the curve for Lake Erie, wherein, it will be noticed, the crest or flood stage for each year from 1895 to 1898 is somewhat higher than for the year immediately preceding.

The annual rise in the Great Lakes begins with the breaking up of ice in the tributary rivers and small streams, and the maximum or flood stage is generally reached in midsummer. Owing to marked climatic differences between the northern and southern portions of the Lake region, the spring rise begins about a month and a half earlier on Lake Erie, the most southern lake, than it does on Lake Superior, the most northern. The time of high water on the last-named lake is also from one to three months later than on Lake Erie. The period of replenishment on all of the lakes, except Superior, is from March to June; on Superior from April to September. As soon as high water is reached the lakes begin to fall, slowly at first, but quite rapidly as the winter season approaches.

The annual rise and the nonperiodic variations are doubtless due to atmospheric influences, the most important of which are precipitation, temperature, and evaporation. Changes in lake level may be also due to other causes, such as an increase in the cross section of the outlet or an undue amount of ice in the river channels. Changes in level due to alterations in the outlets of Lakes Huron and Erie are more or less probable. Lake Superior, however, is so situated with respect to its outlet that it should respond rather freely to the atmospheric conditions that prevail over its watershed. For that reason particular attention will be paid in what follows to fluctuations in that lake.

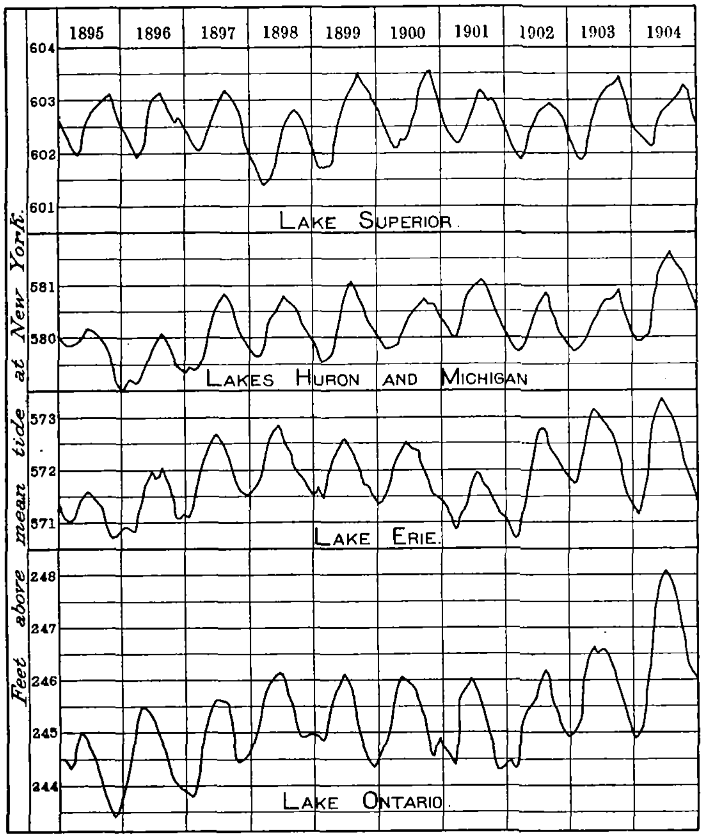

Fig. 1.—Fluctuations in level of the Great Lakes from 1895 to 1904. (By courtesy of the United States Lake Survey.)

The accompanying diagram, fig. 1, shows the fluctuations in level of the Great Lakes from 1895 to 1904. The diagram is based upon the corrected lake levels as reported by the United States Lake Survey, except that final readings for 1904 are not yet available. The low water of 1895 and 1896, as shown by the diagram, was due to adverse atmospheric conditions, viz: persistent drought coupled with periods of abnormally high temperature and greatly increased evaporation. The period of replenishment in 1895 brought very little water into the lakes. The inflow of Lakes Michigan and Huron, which in a normal year is sufficient to raise the level of those lakes a little more than a foot, caused a rise in that year of less than half a foot. Assuming that the discharge through the St. Clair River and the loss by evaporation were not greater than in former years, it will readily be seen that the winter minimum, by reason of the greatly reduced summer maximum, must be considerably lower than for the previous year, as was actually the case. To overcome the loss of water in Lakes Michigan and Huron, due to the adverse conditions extending through several years, it is necessary that favorable conditions prevail for a corresponding term. As may be seen from the diagram, high water was not reached until 1899.

The drought was not so severe in the Lake Superior watershed as in more southern districts, and that lake did not fall much below the mean level until the winter of 1897–8. The latter part of 1897 was very dry, and this period of dryness was followed by an exceptionally warm, open winter. The effect of a warm winter is to greatly increase the opportunity for evaporation. As elsewhere shown by the writer, the difference between the possibilities of evaporation in a very warm winter and a very cold winter, in the Lake Superior region, may amount to 3.5 inches. The winter of 1898–9, succeeding the dry season of 1897–8,.was colder than the average, with precipitation rather below the normal until March, 1899, when heavy snow fell. The writer had occasion to say (Lake Chart, 1899, W. B. No. 213) in discussing the high water that occurred on Lake Superior in 1899:

The precipitation in the Lake Superior basin and on the lake itself was a little more than 29 inches, or about an inch above the normal. In some parts of the basin, as on the Keweenaw Peninsula, there was an excess of from six to eight inches. On the Canadian side, the greatest excess occurred at White River, diagonally across the lake from Keweenaw Point. We may therefore infer that over a considerable portion of the surface of the lake the precipitation exceeded the normal by at least three inches.

The snowfall of the season, October, 1898, to May, 1899, averaged for the whole basin 78.1 inches, of which 26 per cent fell during March, 1899. The cold weather during the first half of April prevented the snow from rapidly disappearing and retarded evaporation. It is quite probable, therefore, that when the snow did melt a large proportion of it eventually found its way into the lake.

In 1900 Lake Superior reached practically the same height as in 1899, although the result was attained in a different way, as may be gleaned from the following excerpt from the Lake Chart for 1900 (W. B. 237):

The winter precipitation was deficient in the upper Lake region, especially in the watersheds of Lakes Superior and Huron. The snowfall on the average for these lakes, including land areas tributary thereto, was about a foot and a quarter less than during the preceding winter. The spring and early summer rains likewise fell short of the normal, by small amounts it is true, yet the accumulated deficiency in the Lake Superior basin from November 1, 1899, to June 30, 1900, was about five and a half inches. The computed evaporation for the same period at Duluth was 15.5 inches as against 12.4 for the corresponding period of the preceding year; Marquette, 13.5 inches as against 10.9 for the preceding year; Saulte Ste. Marie, 13.0 as against 9.0 for the preceding year.

The level of Lake Superior for November, 1899, was 602.68 feet above mean tide at New York City, the highest mean level for that month reached since 1876. The changes in level during subsequent months, according to observations made by officials of the United States Lake Survey, are as follows:

Changes in level of Lake Superior with precipitation departures, December, 1899, to December, 1900.

Date.	Rising or falling.	Precipitation above or below normal.	Date.	Rising or falling.	Precipitation above or below normal.
	Feet.	*Inches.*		*Feet.*	*Inches.*
December, 1899	—0.21	+0.6	July, 1900	+0.18	+1.1
January, 1900	—0.39	—0.2	August, 1900	+0.36	+2.0
February, 1900	—0.19	—0.3	September, 1900	+0.52	+2.4
March, 1900	—0.22	—0.2	October, 1900	+0.08	—0.5
April, 1900	—0.10	—0.7	November, 1900	—0.03	....
May, 1900	+0.17	—1.6	December, 1900	—0.38	....
June, 1900	+0.06	—1.4			

Thus we see that the level of the lake fell continuously until May, when a rise of 0.17 foot, about half the normal rise for that month, was noted. The normal rise, May to June, is 0.30 foot; the actual rise was 0.06 foot. Precipitation, as may be seen from the above table, was continuously below normal from January to June, both inclusive, but beginning with July and continuing through August and September, heavy rains fell in the Superior watershed, the accumulated excess for the three months being 5.5 inches. The computed evaporation during the same months was about the same as for the corresponding period a year ago. Assuming that the discharge through the St. Marys River was normal, the excess of rain that fell on the water surface of the lake above evaporation must have caused the marked increase in level shown in the table over and above the normal increase, July to October. The normal rise of the latter period is but 0.07 foot. The actual increase was 0.96 foot. Deducting the normal increase, there still remains a rise in the level of the lake of about eleven inches from July to October. It is difficult to attribute this rise to any other agency than the actual precipitation on the lake surface.

In the same year, as may be noted by the diagram, the level of Lakes Michigan and Huron fell considerably short of that reached the year previous. The atmospheric precipitation in both basins, particularly the snowfall, was below the average.

Passing now to the high water of 1904, it may be remarked that the atmospheric conditions of the winter of 1903-4 and during the spring of 1904 were such as would conspire to produce high water on the Great Lakes.

The winter of 1903-4 was characterized by severe and continuous cold weather and heavy snow. The latter blanketed practically the whole of the several watersheds and increased in depth as the winter progressed, since there was practically no loss except by evaporation. The snowfall was very heavy in the Lake Huron basin, especially on the higher lands of Ontario, immediately east of Lake Huron. This district was covered in December by a snow covering that probably averaged four feet in depth. In January and February, owing to the absence of thaws, the thickness of the snow covering increased. At the end of February, 1904, the entire Lake region, save the extreme southern portion, was covered by snow, the depth ranging from 5 to 60 inches. In March, although the weather in the southern portion of the Lake region moderated somewhat, cold, stormy weather, with considerable snow, continued in Canadian districts and in northern Wisconsin and northern Michigan. At the close of that month there were from 24 to 30 inches of snow on the ground in Muskoka and Nipissing districts. In southern Ontario, while the remains of drifts were still to be seen, the snow had practically disappeared. On the United States side, except in northern Michigan and northern Wisconsin, there was no snow on the ground.

In April the weather on the Canadian side was exceedingly cold and wet; the temperatures went well above the freezing point in the daytime, but the night temperatures were low enough to cause frost or freezing, especially in northern districts. The ice in the streams of southern and central Ontario broke up about the first of the month; in the Lake Superior watershed and north of Georgian Bay there was very little thawing until near the close of the month.

The stage of water on all of the lakes during the season of navigation just closed was higher than has been experienced for a number of years, the single exception being Lake Superior, which was not quite so high as in 1899, 1900, or 1903. The greatest rise, as compared with 1903 stages, occurred on Lakes Michigan, Huron, and Ontario. The last named for July, 1904, was three and one-half feet above the stage for the corresponding month of 1895, and both Lakes Huron and Michigan were considerably more than a foot above the July stages of that year.

More water came into the lakes, except possibly Superior, this year than for a number of years previous. The rise in Michigan from March to April was a little less than six inches; on Huron a little more than six inches; on Erie about thirteen inches, while on Ontario it was a little over fifteen inches. These figures, however, because of the varying size of the lakes, give no idea of the actual amount of water that flowed into the respective lakes. Remembering that a sheet of water an inch in thickness weighs 72,516 tons (of 2000 pounds each) per square mile, we can easily reduce the inflow of the several lakes to a convenient unit of comparison. Selecting a cubic mile of water as such unit and reducing the increase in level from March to April to terms of that unit, we find that the increase in the level of Lake Huron, roughly speaking, amounted to 2.2 cubic miles of water; Lake Michigan, 1.9; Lake Huron, 2.1; Lake Ontario, 1.9. For the period of replenishment the inflow into Lake Superior was approximately 6.6 cubic miles; Michigan, 5.4; Huron, 6.7; Erie, 2.7, and Ontario, 3.5.

In the opinion of the writer, based on the meteorological conditions that have prevailed during the winter just closed, the outlook for the coming season of navigation is not favorable to a continuation of the high water of 1904, although the season will probably rank as one of relatively high water, especially on the upper lakes. The difference between the levels of 1904 and 1905, due to atmospheric conditions, will naturally be most pronounced on Lakes Erie and Ontario where they may amount to half a foot or more.

RECENT PAPERS BEARING ON METEOROLOGY.

Mr. H. H. KIMBALL, Librarian and Climatologist.

The subjoined titles have been selected from the contents of the periodicals and serials recently received in the Library of the Weather Bureau. The titles selected are of papers or other communications bearing on meteorology or cognate branches of science. This is not a complete index of the meteorological contents of all the journals from which it has been compiled; it shows only the articles that appear to the compiler likely to be of particular interest in connection with the work of the Weather Bureau. Unsigned articles are indicated by a ——.

American Journal of Science. New Haven. 4 series. Vol. 19.
—— Possible variation in solar radiation. [Extract from report of S. P. Langley.] Pp. 246–248.

Astrophysical Journal. Chicago. Vol. 21.
Maunder, E. Walter The solar origin of terrestrial magnetic disturbances. Pp. 101–115.
Hale, George E. A study of the conditions for solar research at Mount Wilson, California. Pp. 124–150.
Hale, George E. The solar observatory of the Carnegie Institution of Washington. Pp. 151–172.

Geographical Journal. London. Vol. 25.
Crostwait, H. L. A journey to Lake San Martin, Patagonia. Pp. 286–291.
Herbertson, A. J. The major natural regions: an essay in systematic geography. [Climate.] Pp. 304–306.

Journal of the Franklin Institute. Philadelphia. Vol. 59.
—— Magnetic storms and sun spots. [Note on work of E. W. Maunder.] P. 216.

Knowledge. London. New Series. Vol. 2.
Shackleton, W. The coming total eclipse. Pp. 45–47.
—— Radium, the cause of the earth's heat. [Note on article of E. Rutherford.] P. 61.

Proceedings of the Royal Society. London. Vol. 74.
Cave-Browne-Cave, F. E. On the influence of the time factor on the correlation between the barometric heights at stations more than 1000 miles apart. Pp. 403–413.

Quarterly Journal of the Royal Meteorological Society. London. Vol. 31.
Boyds, Charles W. R. Meteorological observing in the Antarctic regions. Pp. 1–14.
Brodie, Frederick J. Decrease of fog in London during recent years. Pp. 15–28.
—— Discussion of meteorological observations in relation to solar phenomena. P. 28.
Holmes, R. L. Hurricane in Fiji, January 21–22, 1904. Pp. 29–38.
Thomas, J. Lynn. Two cases of lightning-stroke, July 17, 1903. Pp. 55–60.
—— A legal decision as to damage by lightning and wind. Pp. 60–62.
—— Speculation in rain. P. 62.
Assmann, —. A kite struck by lightning at Hamburg. [Translation of note of Assmann.] P. 75.

School Science and Mathematics. Chicago. Vol. 5.
Cox, Henry J. Recent advances in meteorology. Pp. 159–167.

Scientific American. New York. Vol. 92.
Putnam, B. L. Grandfather's barometer. P. 179.

Scientific American Supplement. New York. Vol. 59.
Eliot, John. Meteorology in the British Empire. Pp. 24373–24374.
Eliot, John. Meteorology in the British Empire. P. 24386.
Clerke, Agnes M. Our solar system. Pp. 24386–24387.

Science. New York. Vol. 21.
Rotch, A. Lawrence. The temperature and drift of the air at great heights above the American Continent, obtained by means of registration balloons. [Preliminary report.] P. 335.
Ward, R. DeC. The teaching of meteorology. [Note on address of Cleveland Abbe.] Pp. 336–337.
Ward, R. DeC. Meteorological results of the Blue Hill kite work. [Review of work of H. H. Clayton.] Pp. 433–435.

Symons's Meteorological Magazine. London. Vol. 40.
—— The high barometer of January, 1905. Pp. 2–6.
Bonacina, L. C. W. The great problem of meteorology. Pp. 7–10.
Shaw, W. N. Autumn rainfall and yield of wheat. Pp. 10–12.
—— Our rainfall averages. Pp. 14–15.

Science Abstracts. London. Vol. 29.
Eb[ert, H.] Luftelektrische Messungen bei zwei Ballonfahrten. [Abstract of work of H. Gordien.] Pp. 208–209.